(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 October 2002 (10.10.2002)

PCT

(10) International Publication Number
WO 02/079863 A2

(51) International Patent Classification⁷: G02F 1/01, 1/225

(21) International Application Number: PCT/GB02/01341

(22) International Filing Date: 20 March 2002 (20.03.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0108129.8 31 March 2001 (31.03.2001) GB

(71) Applicant (*for all designated States except US*): **BOOKHAM TECHNOLOGY PLC** [GB/GB]; 90 Milton Park, Abingdon, Oxfordshire OX14 4RY (GB).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **ONISCHENKO, Alexander, Ivanovich** [RU/GB]; 17c Martyr Road, Guildford, Surrey GU1 4LE (GB). **PECHSTEDT, Ralf, Dieter** [DE/GB]; 2 Wasbrough Avenue, Wantage, Oxfordshire OX12 9BD (GB). **GAHAN, David, Francis** [GB/GB]; 1 The Croft, West Hanney, Nr Wantage, Oxfordshire OX12 0LD (GB). **ASGHARI, Mehdi** [GB/GB]; 29 Westlecot Road, Swindon, Wiltshire SN1 4EZ (GB).

(74) Agent: **HARDING, Richard, Patrick**; Marks & Clerk, 4220 Nash Court, Oxford Business Park South, Oxford, Oxfordshire OX4 2RU (GB).

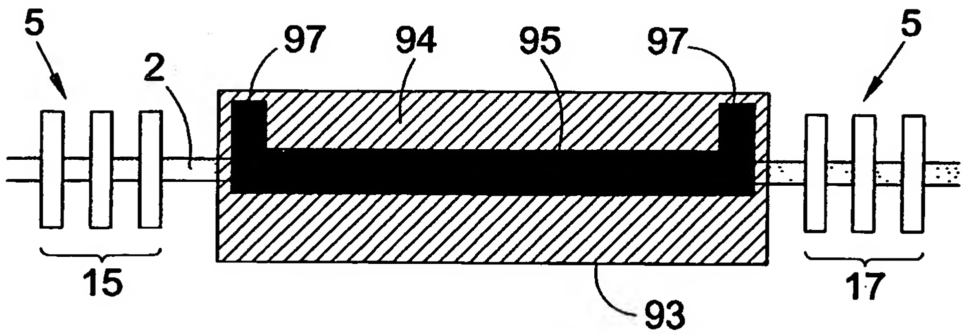
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*
— *entirely in electronic form (except for this front page) and available upon request from the International Bureau*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: OPTOELECTRONIC FILTERS



(57) Abstract: An optoelectronic filter formed on a SOI chip comprises a silicon rib or ridge waveguide (2) formed in a silicon layer for conducting a light beam along an optical transmission path, a silica confinement layer providing optical confinement in a vertical direction, and a silicon substrate. Deep trenches (5) are etched perpendicularly to the waveguide direction up to the confinement layer (3) to form two distributed Bragg reflector (DBR) elements (15 and 16) separated by a Fabry-Perot (FP) cavity. The trenches (5) form air gaps in the optical transmission path which results in wavelength-dependent reflection of the light beam. Furthermore a heater (93) is provided for controlling the temperature of the part of the waveguide (2) between the DBR's in order to tune the passband of the filter. Such a filter can be readily tuned to the required passband, and can be manufactured using only a small number of manufacturing steps.

WO 02/079863 A2

"Optoelectronic Filters"

This invention relates to optoelectronic filters, and is concerned more particularly, but not exclusively, with optoelectronic filters utilising distributed Bragg reflectors (DBRs) in Fabry-Perot cavities.

It will be understood that the terms "optical" and "optoelectronic" are used in this specification in a non-specific sense, that is so as to cover use with radiation in the visible and non-visible parts of the spectrum, and so as not to be limited to use with visible light.

In integrated optical circuits used in optical communications, for example, light is transmitted down waveguides formed in materials such as silicon. A silicon waveguide structure typically comprises a rib or ridge formed in the upper silicon layer of a SOI (silicon-on-insulator) chip, the rib having a top surface and side walls and serving to confine an optical transmission along the waveguide.

Various types of optoelectronic device may be integrated in such optical circuits in order to vary the amplitude, pulse length or phase of the optical transmission along the waveguide from a light source, such as a light-emitting diode or a laser diode. One such optoelectronic device is a wavelength-dependent filter which may be used to pass light of wavelength within a narrow passband, whilst preventing the passage of light of wavelengths outside this passband.

Accelerating development within the information technology (IT) field demands newer and better technologies to support communication and computer data transmission and processing. One such technology is optical communications, and one of the methods for increasing data rates in optical communications is wavelength division multiplexing (WDM) in which different data channels within a light signal transmitted along a single optical fibre or waveguide are differentiated according to the wavelength band of the transmitted light corresponding to that channel. Signal processing in such WDM systems involves multiple combination and/or separation of

the individual channels, and thus the key components of any WDM system are the optical filters providing selection of the distinct wavelength bands corresponding to the different data channels from the whole spectrum of the transmitted light signal. Optical filters are also necessary for further processing of the signals of different wavelength bands corresponding to such separated channels. An ideal optical filter can be characterised by a perfectly flat passband that would transmit all of the light energy of the designated range of wavelengths and block any contribution form the rest of the spectrum (so as to minimise any crosstalk from other channels).

Various types of optical filter are available for this purpose, including filters based on distributed Bragg reflectors (DBRs) utilised in a Fabry-Perot (FP) cavity scheme.

Such FP-DBR filters are typically implemented by means of a multilayer surface coating structure defining interfaces between layers of different refractive indices which provide wavelength-dependent reflection and corresponding phase shifting of the light transmission. The design criteria of such filters are discussed in P.W. Baumeister, Applied Optics, Vol. 37, No. 28, pages 6609-14, 1998, and J. Pan et al., Society of Vacuum Coaters 41st Annual Technical Conference Proceedings, ISSN 0737-5921, pages 217-9, 1998.

US 5080503 discloses a DBR-based filter (not in a FP cavity scheme) in which Bragg gratings are embedded in two different positions along the waveguide, the gratings being formed by parts of the waveguide for which the refractive index has been modified by a series of fabrication steps including masking and immersion in a bath of molten salt to change the refractive index of the material. However the fabrication of such filters is complex and is incompatible with conventional fabrication technology used in the production of waveguide-based optical chips. Furthermore the relatively small differences in the refractive indices of the different parts of such filters renders them of only limited use.

US 4963177 discloses a grating-assisted optical waveguide device in which a Bragg grating is formed by masking and by immersing selected parts of the substrate in baths of molten salt to change the refractive index of those parts of the substrate by an ion-exchange process. Such a device suffers from the same disadvantages as the device of US 5080503.

M. Y. Liu and S. Y. Chou, "High Modulation Depth and Short Cavity Length Silicon Fabry-Perot Modulator with Two Grating Bragg Reflectors", Appl. Phys. Lett. 68 (2), 8 January 1996, pp 170-172, disclose a planar waveguide modulator structure consisting of two DBR elements interconnected by a Fabry-Perot (FP) cavity, each DBR element being formed by very narrow trenches extending part of the way through the silicon layer within which the waveguide is formed and providing at least one air gap in the optical transmission path. In order to provide a true single mode (TSM) structure the dimensions of the waveguides and the slots must be very small, and this increases manufacturing complexity as well as limiting the applications of such a structure.

It is an object of the invention to provide an optoelectronic filter which can be tuned to the required wavelengths, and which is particularly suitable for fabrication as a component of an integrated waveguide-based optical chip.

According to the present invention there is provided an optoelectronic filter comprising a substrate, an optical waveguide formed on the substrate for conducting a beam of radiation along an optical transmission path, a filter element in the optical transmission path of the waveguide consisting of two distributed Bragg reflector (DBR) elements separated by a Fabry-Perot (FP) cavity, and phase shifting means for controlling the phase shift along the waveguide between the DBR elements in order to tune the passband of the filter element, the phase shifting means comprising heater means for controlling the temperature of at least a part of the waveguide between the DBR elements.

The use of such phase shifting means is advantageous as it allows the passband of the filter to be finely tuned to the required application. Such tuning requires only local heating to enable the chip as a whole to be kept at a substantially constant temperature and in a fast scanning mode.

Preferably each DBR is formed by at least one trench extending transversely of the optical transmission path and providing at least one air gap in the optical transmission path which results in wavelength-dependent reflection of the beam. Because of the high refractive index contrast between air and the material of the substrate, such a filter design allows high refractivity at the air/material interfaces for incident radiation at angles less than the angle of total reflection, and as a result allows filters of compact size to be produced. Furthermore it is an advantage of such trenches that they assist in containing the heat produced by the heater means in the region in which it is required to heat the waveguide. Such a design can be used to implement a wide range of optical waveguide filters, and in particular allows components of DWDM optical communication systems, such as interleavers, to be produced with an almost ideal passband.

Preferably said at least one trench has a width $w_1 = m_1\lambda_0/4$ where λ_0 is the wavelength corresponding to the maximum reflectivity of the filter and m_1 is an odd integer in the range 1 to 9. Most preferably m_1 is 3. Generally there will be a plurality of trenches spaced apart by a distance $w_2 = m_2\lambda_0/4n$ where λ_0 is the wavelength corresponding to the maximum reflectivity of the filter, n is the effective refractive index for the waveguide mode at the wavelength λ_0 and m_2 is an odd integer in the range 5 to 101.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a schematic diagram showing a view from above of an optoelectronic filter in accordance with the invention;

Figure 2 is a schematic diagram showing a section along the line I-I in Figure 1;

Figures 3 to 7 are diagrams illustrating various filter implementations in accordance with the invention;

Figures 8a to 8f are diagrams illustrating successive steps in a preferred method of fabrication of the filter of Figure 1; and

Figures 9 and 10 are respectively a cross-sectional view and a view from above of a phase shifting element used in the filters of the invention.

The following description will be confined to examples of optoelectronic filters which may be implemented in accordance with the invention by being fabricated on a SOI chip. However it will be well understood to those skilled in the art that it is also possible to implement optoelectronic filters in accordance with the invention using other fabrication technologies and materials other than silicon.

The diagram of Figure 1 shows the top view of a segment of a SOI chip 1 incorporating a silicon rib or ridge waveguide 2 formed in a silicon layer 6 which typically has a thickness in the range of 2 to 10 μm, a silica confinement layer 3 providing optical confinement in a vertical direction, and a silicon substrate 4. Deep trenches 5 are etched perpendicularly to the waveguide direction up to the confinement layer 3 to form a distributed Bragg reflector (DBR). Figure 2 shows a vertical section through one of the trenches 5 from which it is apparent that the trench extends completely through the waveguide 2 and through the supporting layer 6 up to the confinement layer 3 and for some distance either side of the waveguide 2. However, in some embodiments in accordance with the invention, the trench may extend only part of the way through the supporting layer 6 so that it does not extend to the depth of the confinement layer 3. Furthermore the trench may extend transversely to the waveguide at angles other then 90° in some embodiments of the invention.

The DBR may comprise one or more such trenches, the particular embodiment of Figures 1 and 2 having four trenches 5 extending parallel to one another. Furthermore the trenches 5 have identical widths w_1, and are spaced apart by equal distances w_2, which are defined by Bragg resonance conditions:

$$w_1 = m_1\lambda_0/4 \quad \text{and} \quad w_2 = m_2\lambda_0/4n$$

where λ_0 is the wavelength corresponding to the maximum reflectivity R of the DBR, m_1 and m_2 are odd integer numbers, and n is the effective refractive index for the waveguide mode at λ_0. The width w_1 of each trench optimally has a value corresponding to m_1=3 to m_1=9 (m_1=3 being the most optimal), and the distance w_2 optimally has a value corresponding to m_2=5 to m_2=101 (the most optimal depending on the required passband.

R depends on number of trenches M according to the relationship:

$$R = \left(\frac{n^{2M}-1}{n^{2M}+1}\right)^2$$

Furthermore the DBR reflects optical power P in wavelength ranges $\lambda_1 \ldots \lambda_N$ around λ_0 forming a reflection band.

In a practical implementation of such a filter the DBR arrangement is integrated with a Fabry-Perot (FP) cavity to ensure that the filter passes only light within a narrow wavelength band whilst reflecting light of all other wavelengths. Figure 3 shows an integrated optical circuit incorporating a waveguide 12, two identical DBRs 15 and 16, and a phase shifting element (PSE) 17 within a Fabry-Perot (FP) cavity of length w_{FP} formed between the two DBRs. The FP cavity introduces one or more passbands $P(\lambda_{FP})$ within the reflection band of the DBRs 15, 16 around the or each FP resonance frequency:

$$\lambda_{FP} = 2nw_{FP}/m$$

where m is an integer.

Thus such a FP-DBR structure acts as an optical filter for filtering light of wavelengths $P(\lambda_{FP}, \lambda_1 \ldots \lambda_N)$ so as to transmit light of wavelengths within the or each passband $P(\lambda_{FP})$ and reflect light of other wavelengths $P(\lambda_1 \ldots \lambda_N)$. Furthermore the FP resonance frequency λ_{FP} and the position of the or each passband can be controlled by the PSE 17 within the cavity. Such a PSE enables filters to be produced which are capable of acting as scanning or tunable filters. The PSE can be implemented as an integrated thermal heater which can be fabricated on SOI material.

Figure 4 shows a development of such an integrated optical circuit to enable the reflected optical power to be utilised in further optical processing stages. In this case the integrated optical circuit 20 comprises effectively two identical systems as described with reference to Figure 3 connected in parallel between two 3dB directional couplers 21 and 22. More particularly the circuit 20 comprises two waveguides 23 and 24 connected to respective arms of each coupler 21, 22, and two sets of trenches 32 intersecting both waveguides 23, 24 and forming two DBRs 25 and 26 separated by a FP cavity and two DBRs 27 and 28 separated by a further FP cavity. Each set of trenches 32 may comprise one or more trenches, six such trenches being provided in the example given. The first coupler 21 has an input 29 for the inputted light of wavelengths $P(\lambda_{FP}, \lambda_1 \ldots \lambda_N)$ and an output 30 for the reflected light of wavelengths $P(\lambda_1 \ldots \lambda_N)$ to be outputted for further filtering or some other function in further processing stages, whereas the second coupler has an output 31 for the light of wavelength $P(\lambda_{FP})$ passed by the filter. The 3dB couplers 21 and 22 are directional couplers of a known type, for example as shown in Figure 3 of US 4963177.

The shape of the passband of a single FP-DBR filter is predominantly defined by the number of trenches M in the DBRs and the length of the FP cavity w_{FP}. A wider range of passband shapes, such as may be required for such important applications as interleavers in DWDM systems for example, can be achieved by combining of the individual FP filters. Figure 5 shows an integrated optical circuit 50 comprising N individual FP-DBR filters connected in series. More particularly such a circuit 50 comprises N + 1 DBRs 51, that is DBR_1, DBR_2, DBR_3 ….. DBR_{N+1}, separated by N FP

cavities 52, that is FP_1, FP_2 ...... FP_N., distributed along a waveguide 53. As in the case of the embodiment of Figure 3, such an arrangement acts as an optical filter for filtering light of wavelengths $P_{in}(\lambda)$ so as to transmit light of wavelengths within the or each passband $P_{out}(\lambda)$ and reflect light of other wavelengths $P_{in}(\lambda) - P_{out}(\lambda)$.

Figure 6 shows a development of such an integrated optical circuit to enable the reflected optical power to be utilised in further optical processing stages. In this case the circuit 60 comprises effectively two identical systems as described with reference to Figure 5 connected in parallel between two 3dB directional couplers 61 and 62. More particularly the circuit 60 comprises two waveguides 63 and 64 connected to respective arms of each coupler 61, 62, and two sets of FP-DBR circuits 65 and 66, each comprising N+1 DBRs, that is DBR_1, DBR_2, DBR_3 ..... DBR_{N+1}, separated by N FP cavities, that is FP_1, FP_2 ...... FP_N., distributed along a respective one of the waveguides 63, 64. As in the case of the embodiment of Figure 4, the circuit incorporates a first coupler 61 having an input for the inputted light of wavelengths $P_{in}(\lambda)$ and an output for the reflected light of wavelengths $P_{in}(\lambda) - P_{out}(\lambda)$ to be outputted to the further processing stages, and a second coupler 62 having an output for the light of wavelength $P_{out}(\lambda)$ passed by the filter. It will be appreciated that the circuit of Figure 4 is simply the equivalent of the circuit of Figure 6 for the case where N=1 corresponding to a single stage FP filter.

The shape of the passband can alternatively be enhanced by the combining of individual FP filters in cascade as shown in the circuit of Figure 7. In this case the integrated optical circuit 70 comprises N individual FP-DBR filter stages 71, each stage comprising two DBRs separated by a FP cavity, connected in cascade and connected by respective waveguides 72 to a N X 1 coupler 73 (using a circuit arrangement similar to that shown in Figure 13 of IEEE J.of Sel. Top. in Quant. Elect., Vol. 2, No. 2, 1996, page 151). Such an arrangement acts as an optical filter for filtering light of wavelengths $P_{in}(\lambda)$ supplied to the input 75 so as to transmit light of wavelength $P_1(\lambda)$ from the output of the first FP-DBR filter stage 71, light of wavelength $P_2(\lambda)$ from the output of the second FP-DBR filter stage 71, and light of wavelength $P_N(\lambda)$ from the output of the last FP-DBR filter stage 71. The optical spectra of all the filter stages 71,

$P_{1...N}(\lambda)$, are combined in the coupler 73 to produce a desirable shape of the whole transmitted spectrum, $P_{out}(\lambda)$, with the reflected light of other wavelengths $P_{in}(\lambda)$ - $P_{out}(\lambda)$ being outputted from the output 74 for further processing.

In the first step of this method a layer of photoresist 80 is applied to a SiO_2 layer 81 on top of an epitaxial layer 82 which in turn overlies a buried SiO_2 layer 83 on the silicon substrate 84, as shown in Figure 8a. The photoresist layer 80 is then exposed through a mask (not shown) and developed prior to being etched, preferably using a dry etch technique, to form five slots 85 in the SiO_2 layer 81, as shown in Figure 8b. The photoresist layer 80 is then removed leaving the SiO_2 layer 81 incorporating the slots 85 in position on top of the epitaxial layer 82, as shown in Figure 8c. The epitaxial layer 82 is then etched to produce five trenches 86 (one more than is shown in Figure 1) using the SiO_2 layer 81 as a mask with the buried SiO_2 layer 83 being used as an etch stop, as shown in Figure 8d. A further layer of photoresist 87 is then applied to the SiO_2 layer 81, and the photoresist layer 87 is exposed through a further mask (not shown) defining the required waveguide pattern. The exposed photoresist is then developed and the SiO_2 layer 81 is selectively etched, as shown in Figure 8e. A suitable deep etching process which may be used in this application is dry plasma etching as disclosed in "High etch rate, deep anisotropic plasma etching of silicon for MEMS fabrication " by T. Pandhumsoporn, L. Wang, M. Feldbaum, P. Gadgil, Alcatel Comptech Inc. Finally, using the SiO_2 layer 81 as a mask, the epitaxial layer 82 is partially etched to produce the waveguide 88, as shown in Figure 8f.

Figure 9 shows a cross-sectional view of a heater 93, which may be used as the PSE 17 of Figure 3 for tuning the filter, incorporated within the waveguide, and Figure 10 is a top view of the FP-DBR cavity incorporating the heater 93. As in Figures 1 and 2, the waveguide 2 is formed on a silicon layer 6 separated from the silicon substrate 4 by a silica (SiO_2) optical confinement layer 3. The heater 93 is formed by a SiO_2 insulating layer 94 on top of the waveguide 2 and a resistive alloy layer 95 on top of the layer 94. The resistive alloy of the layer 95 is preferably Ti/W/Au. As shown in Figure 10, the insulating layer 94 extends within the FP cavity between the trenches 5 of the two DBR's 15 and 17, and the resistive layer 95 is provided with contacts 97 to which a

voltage source is connected for passing a current through the resistive layer 95 to effect local heating of the waveguide 2.

It will be appreciated that the heater 93 may be fabricated as an integral part of the fabrication method already described with reference to Figures 8a to 8f. In this method the insulating layer 94 is formed by oxidising a part of the waveguide in a similar manner to the SiO_2 layer 81 of Figures 8a to 8f, and the resistive layer 95 is deposited on top of the insulating layer 94 and shaped using conventional photoresist masking and etching techniques prior to the bonding of the contacts 97 to the resistive layer 95 in conventional manner. In order to tune the filter an appropriate voltage is applied to the contacts 97 to pass a current through the resistive layer 95 to thereby cause resistive heating of the layer 95 and the section of the waveguide 2 under the layer 95. As a result the refractive index of the waveguide 2 changes due to its temperature dependence (thermo-optic effect) causing a change in the optical length of the section of the waveguide 2 under the layer 95. Thus controlling of the current supply to the heater 93 by an electronic control circuit (not shown) allows the phase of the light outputted by the waveguide 2 to be controlled relative to the phase prior of the input light

Alternatively the heater may be implemented by two similarly doped regions on opposite sides of the waveguide separated by the intrinsic silicon of the waveguide, as described in GB 9815655.7. It is also possible for the PSE to be in the form of a Peltier device in which heating is effected at a junction between two dissimilar materials, for example at a junction between p-doped and n-doped regions of the silicon layer, due to the Peltier effect.

The filters in accordance with the invention are particularly suitable for integration within an integrated optical circuit, and can be used with advantage in a hybrid laser design.

A major advantageous feature of the filters in accordance with the invention is their small size by comparison with wavelength-selecting components based on free diffraction and propagation such as an arrayed waveguide grating (AWG) or various

implementations of the Mach-Zehnder interferometer (MZI) scheme. This permits a reduction in manufacturing cost since more such devices can be fabricated on a single wafer due to their small size. However such filters are not completely equivalent to AWG or MZI filters and cannot replace them in all applications.

Due to the very well-defined filter function of such filters, filters in accordance with the invention are ideal for building various types of optical spectrum analyser (OSA), as well as for optical channel monitors (OCM). In the case of OCMs the optical power can be measured not by integrating over the complete spectral span of a channel, but rather by sampling the channel at the wavelength of the filter. This wavelength can be scanned or tuned by means of thermal control over the whole spectral range.

Filters in accordance with the invention can also be used in multiplexers or demultiplexers based on so-called interleavers having a periodic comb-like rejection function. By suitable design of the parameters (cavity length, number of DBRs, number of trenches, width and spacing of trenches in each DBR) of the filters of the invention, it is possible to achieve an almost ideal passband, so that filters can be produced which are superior to the MZI filters conventionally used for such interleavers.

CLAIMS:

1. An optoelectronic filter comprising a substrate, an optical waveguide formed on the substrate for conducting a beam of radiation along an optical transmission path, a filter element in the optical transmission path of the waveguide consisting of two distributed Bragg reflector (DBR) elements separated by a Fabry-Perot (FP) cavity, and phase shifting means for controlling the phase shift along the waveguide between the DBR elements in order to tune the passband of the filter element, the phase shifting means comprising heater means for controlling the temperature of at least a part of the waveguide between the DBR elements.

2. A filter according to claim 1, wherein the heater means comprises a resistive track and means for applying a heating current to the resistive track.

3. A filter according to claim 2, wherein the resistive track comprises an insulating layer, and a layer of alloy material on top of the insulating layer.

4. A filter according to claim 3, wherein the resistive track incorporates Ti/W/Au alloy material.

5. A filter according to claim 2, 3 or 4, wherein the resistive track is applied to one side of the waveguide.

6. A filter according to claim 5, wherein similar resistive tracks are applied to two opposite sides of the waveguide.

7. A filter according to claim 1, wherein the heater means comprises two similarly doped regions on opposite sides of the waveguide separated by a region of the waveguide and means for applying a heating current between said doped regions.

8. A filter according to any preceding claim, wherein the heater means includes an electronic control circuit for controlling the current applied to the heater means to control the phase shift applied.

9. A filter according to any preceding claim, wherein each DBR element is formed by at least one trench extending transversely across the optical transmission path and providing at least one air gap in the optical transmission path which results in wavelength-dependent reflection of the beam.

10. A filter according to any preceding claim, which includes a plurality of filter assemblies each of which comprises two DBR elements interconnected by a Fabry-Perot (FP) cavity, each DBR element being formed by at least one trench extending transversely across the optical transmission path and providing at least one air gap in the optical transmission path.

11. A filter according to claim 10, wherein at least some of the filter assemblies are connected in series.

12. A filter according to claim 10 or 11, wherein at least some of the filter assemblies are connected in parallel.

13. A filter according to claim 10, 11 or 12, wherein at least some of the filter assemblies are connected in parallel between first and second optical couplers, the first coupler providing an input for the optical signal $P_{in}(\lambda)$ to be filtered and an output for the reflected signal $P_{in}(\lambda)$ - $P_{out}(\lambda)$, and the second coupler providing an output for the filtered signal $P_{out}(\lambda)$.

14. A filter according to claim 13, wherein the couplers are 3dB directional couplers.

15. A filter according to claim 10, 11, 12, 13 or 14, wherein at least some of the filter assemblies are connected in cascade such that the reflected signal outputted by at

least one of the assemblies is filtered by at least one subsequent assembly and each assembly provides an output signal corresponding to a respective wavelength band.

16. A filter according to any preceding claim, wherein the waveguide is a rib or ridge waveguide.

17. A filter according to any preceding claim, which is formed by silicon-on-insulator (SOI) technology.

18. An integrated optical circuit incorporating at least one optoelectronic filter according to any preceding claim.

19. A circuit according to claim 18, wherein said at least one optoelectronic filter is incorporated in a dense wavelength division multiplexing (DWDM) system.

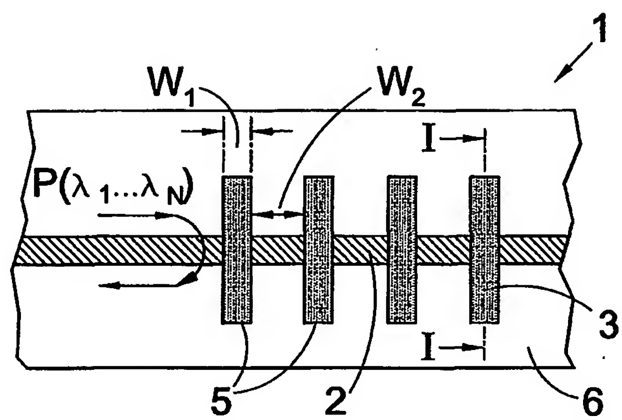


Fig.1

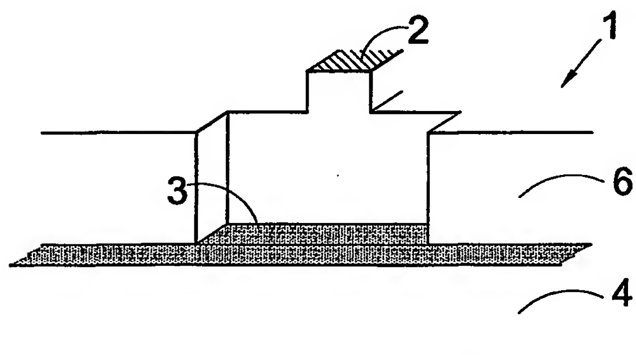


Fig.2

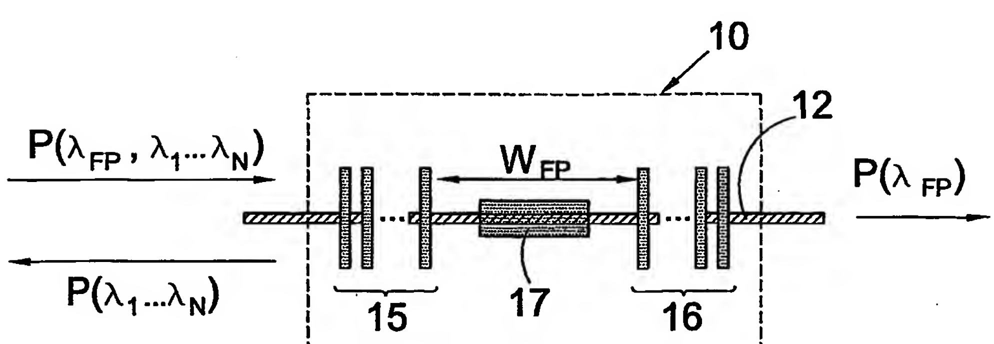


Fig.3

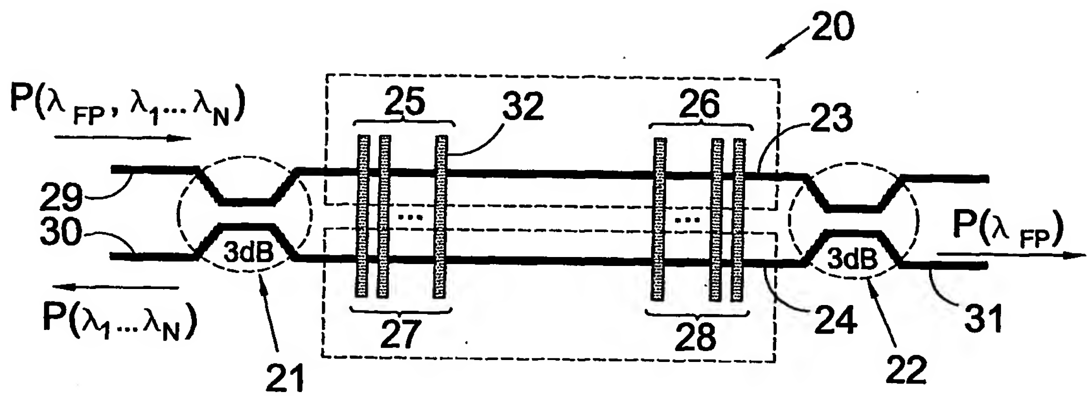


Fig.4

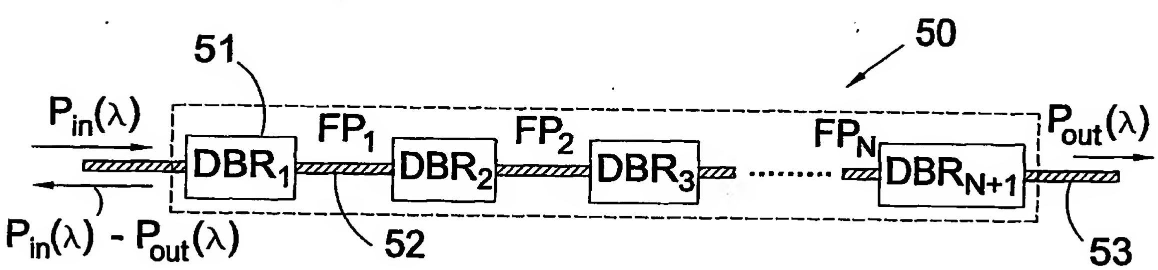


Fig.5

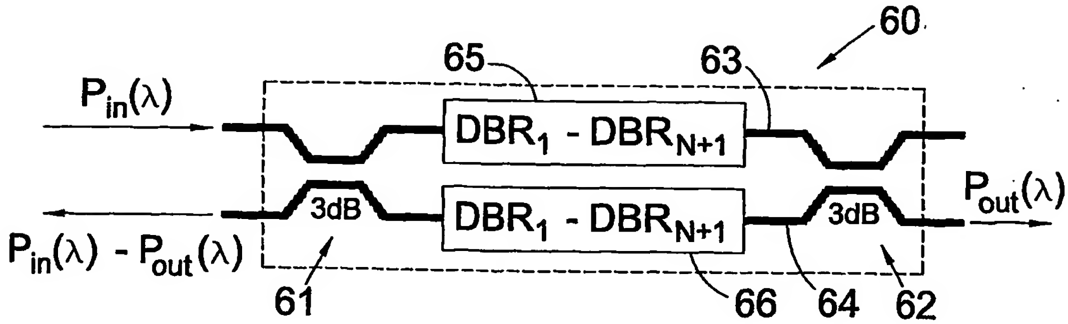


Fig.6

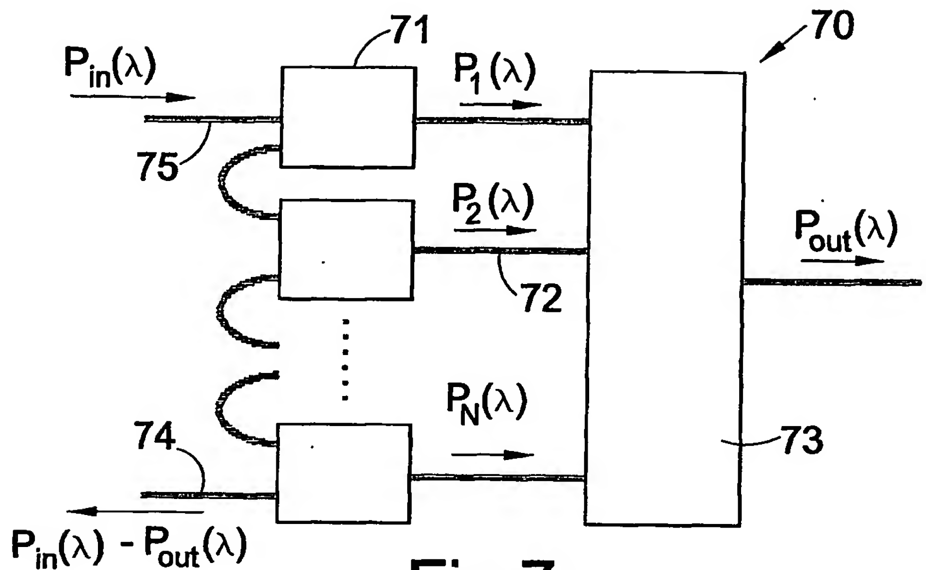


Fig.7

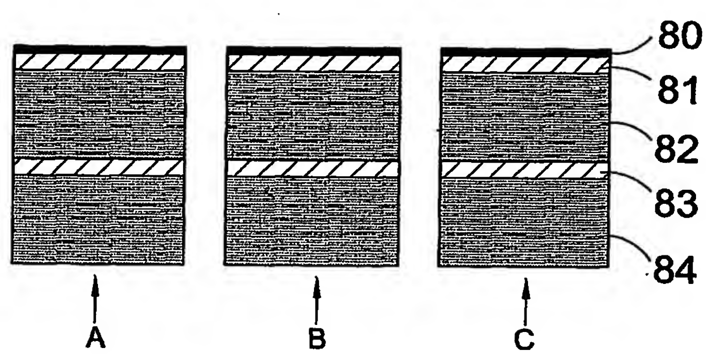


Fig.8a

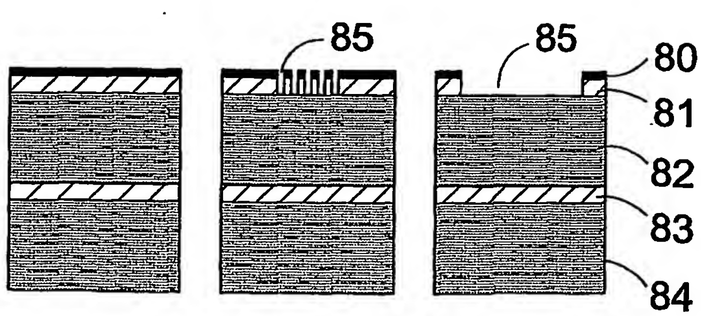


Fig.8b

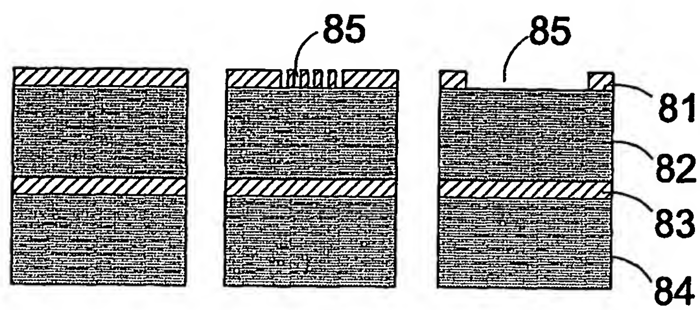


Fig.8c

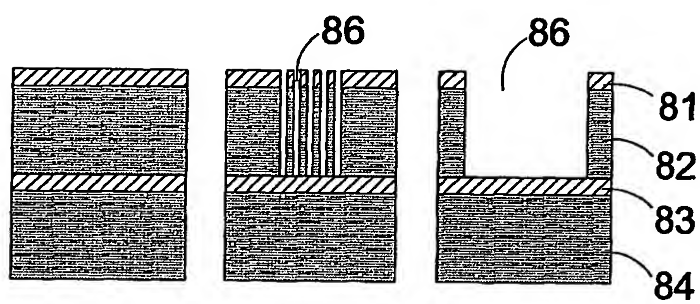


Fig.8d

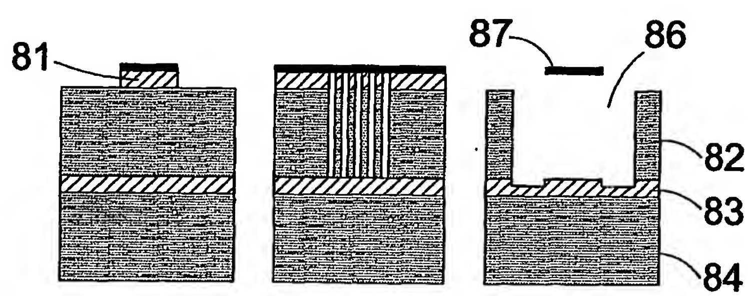


Fig.8e

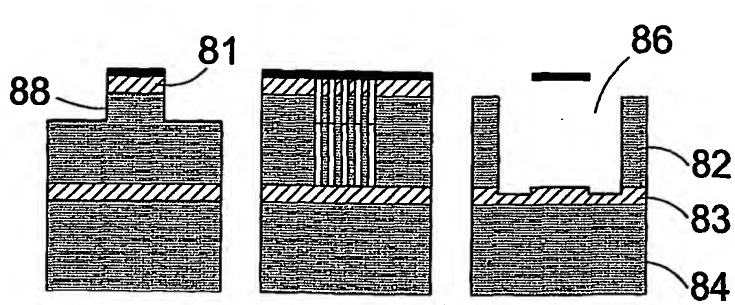


Fig.8f

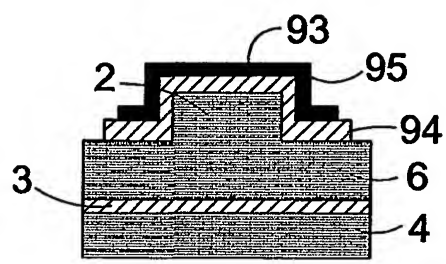


Fig.9

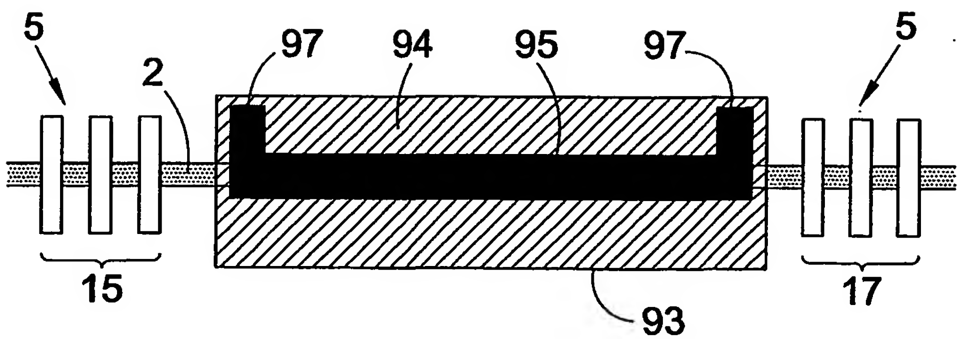


Fig.10